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Wastewater collection system infrastructure research needs

Anthony N. Tafuri, P.E.*

Ariamalar Selvakumar, Ph.D., P.E.**

U.S. Environmental Protection Agency,

National Risk Management Research laboratory,

Urban Watershed Management Branch,

2890 Woodbridge Avenue, Edison, NJ 08837.

Abstract

Many of the wastewater collection systems in this country were developed in the early part of this century. Maintenance, retrofits, and rehabilitations since then have resulted in patchwork systems consisting of technologies from different eras. More advanced and cost-effective methods to properly rehabilitate these systems must be considered to guarantee sustainability into the future. Achieving sustainable development presents a challenge to deliver new and innovative infrastructure and facilities needed to serve society while protecting the environment. In the context of this paper, sustainable development would provide new and improved solutions to existing and emerging problems associated with wastewater collection system infrastructure. Such solutions would, for example, include consideration of innovative approaches and practices for identifying and rehabilitating problems in existing systems and ways of preventing these problems in new construction. The paper focuses on technical issues and research needs in three major areas: (1) assessment of system integrity; (2) operation, maintenance, and rehabilitation; and (3) new construction. Many of the issues and needs discussed were identified at a USEPA sponsored experts workshop on infrastructure problems associated with wastewater collection systems.

Keywords: Wastewater collection system, system integrity, flow monitoring, condition assessment, rehabilitation, pipelines, manholes, infiltration and inflow, new construction.

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*Corresponding Author. Tel.: (732) 321 6604; Fax: (732) 321 6640.

E-mail address: tafuri.anthony@epa.gov

1. Introduction

The aging condition of our cities and an associated deterioration of infrastructure (buildings, highways, utility systems, water distribution systems, sewerage systems) leads to an emerging research area addressing how best to design, construct, maintain and repair both existing and new infrastructure. The costs associated with maintaining infrastructure are staggering; the national investment in sewers alone approaches $1.8 trillion (ASCE, 1996). Sewer pipeline stoppages and collapses are increasing at a rate of approximately 3% per year. Roots that puncture and grow inside pipes cause over 50% of the stoppages, while a combination of roots, corrosion, soil movement and inadequate construction are the cause of most structural failures (ASCE, 1994). There are an estimated six to eight hundred thousand miles of sewer pipes in the United States. According to a study conducted by the Urban Institute (1981), approximately 50 major main breaks and 500 stoppages occur per 1000 miles per year, amounting to an estimated 30,000 breaks and 300,000 stoppages annually. Deterioration of jointing materials, pressure surges, disturbance by construction or direct tapping, and seismic activity also contribute to collection line failures. These problems result in approximately 75% of the nation's piping systems functioning at 50% of capacity or less (ASCE, 1994).

Besides stoppages and collapses, infiltration and inflow (I/I) can rob capacity in a sanitary sewer system and negatively affect operation of the entire sewerage system. I/I are extraneous flows that enter the sewer system. Inflow is generally defined as stormwater that enters the collection system through direct connections (e.g., roof leaders, cellar and yard area drains, foundation drains, commercial and industrial so-called "clean water" discharges, drains from springs and swampy areas, etc.). Infiltration is defined as water that enters from the ground. In the late 1980s, the term "rainfall-induced infiltration" was first used to describe infiltration with flow characteristics resembling inflow (i.e., a rapid increase in flow which coincides with a rain event). Rainfall-induced infiltration results when stormwater runoff causes a rapid groundwater recharge around sewers, including manholes and building connections, which then enters the system through defective pipes, pipe joints, or manhole walls.

I/I can greatly increase flows and cause unnecessary burdens on the treatment plant. In some systems, sewerlines become overloaded and uncontrolled sanitary sewer overflows (SSOs) occur at unspecified locations. Since most sanitary sewers do not have overflow structures designed into the system, SSOs often occur through manholes and defective lines in residential neighborhoods causing backups into homes and streets. I/I also causes surcharging of wastewater treatment plants and pumping stations. In comparison to combined sewer overflows, SSOs generally contain higher percentages of raw sanitary sewage (which can contain high levels of infectious (pathogenic) microorganisms, suspended solids, toxic pollutants, floatables, nutrients, oxygen-demanding organic compounds and fecal matter, oil and grease, and other pollutants) and a lower level percentage of stormwater. SSOs represent a human health risk because of pathogenic organisms. In San Diego, CA, SSOs have threatened drinking water supplies, creating the potential for serious adverse public health impacts (Golden, 1996). The oxygen-demanding compounds associated with SSOs can also affect the aquatic environment. In Alabama, SSOs have had an adverse impact on the number and range of species found in the Cahaba River (Cahaba River Society, 1993). They also reported low levels of dissolved oxygen and algal blooms.

Old sewer systems, constructed before 1970 using mortar or mastic jointing materials, can substantially contribute to exfiltration as well as to I/I. Exfiltration can occur when the elevation of the sewer liquid level is above the groundwater table. This positive elevation head can cause raw sewage to exfiltrate through open joints to ground water and other areas of the environment. Stoppages and collapses can cause flows to exit the sewerline and concentrate in the trenches dug for the sewerlines or other utility lines. The flow is then conveyed by gravity along the trench to surface water or the flow can infiltrate into the ground and threaten drinking water supplies. Loose joints and deteriorated pipes are the main source for the flows to exit the sewer; house lateral connections to street sewers are other prime points of leakage. Exfiltration from both combined and sanitary sewers can be a substantial source of pollution in terms of impact on groundwater and surface water quality.

The Clean Water Act (CWA) prohibits point-source discharges of pollutants to waters of the United States unless authorized by a National Pollutant Discharge Elimination System permit. Thus, unpermitted discharges from sanitary sewer systems, i.e., SSOs, violate the CWA. This is true whether the discharge is directly to surface water or indirectly through ground water hydrologically connected to surface waters. Under the Federal Advisory Committee Act, the Urban Wet Weather Flows Advisory Committee subcommittee was formed to provide recommendations on how to address issues associated with SSOs, including deciding between sewer rehabilitation and treatment options to control SSO pollution (USEPA, 1996).

The application of new and advanced technologies can provide more cost-efficient and environmentally conscious solutions to the problems associated with deteriorating wastewater collection systems. Research is critical to accomplish this. This paper identifies related technical issues and research needs in three major areas: (1) assessment of system integrity; (2) operation, maintenance, and rehabilitation; and (3) new construction. The material presented is in part the results of an experts workshop on infrastructure problems in wastewater collection systems sponsored by the Water Supply and Water Resources Division of EPA’s National Risk Management Research Laboratory (USEPA, 1998a).

2. Assessment of system integrity

In order for municipalities to cost-effectively plan, organize, and implement a maintenance and renewal effort, they will need improved information on the condition of the pipe system. A thorough assessment is required to determine the extent of the problem and to evaluate alternative approaches and costs for rehabilitation versus replacement versus storage-treatment options. The process involves two broad, but closely related areas: flow monitoring and physical condition assessment.

2.1. Flow monitoring

Flow monitoring in wastewater collection systems may be conducted for a variety of purposes, including the determination of total system flows, customer billing, identification of capacity problems, monitoring of system performance for operation and maintenance, detection and quantification of overflows or bypasses, measurement of peak wet weather flows and I/I, and calibration of flow models. One of the most widespread uses of flow monitoring in wastewater collection systems is for quantifying wet weather flows (WWFs) and I/I. Two major types of gravity flow meters are involved: area-velocity meters and critical depth meters. Critical depth devices include flumes and weirs. Area-velocity devices utilize a number of different technologies for depth and velocity measurement while critical depth devices just use depth measurement. Commonly used depth measurement technologies include air bubblers, pressure transducers, and ultrasonic transducers. Velocity measurement technologies include electromagnetic sensors and acoustics devices.

The primary issues relating to flow monitoring technologies are accuracy and reliability. Various physical and hydraulic site conditions such as pipe size, range of flow depths, flow velocities, occurrence of surcharge and backwater conditions, turbulence and other nonuniform flow conditions, pipeline sediment layers, etc., often affect the performance of flow meters. Use of the flow monitoring data requires a good understanding of what accuracy and reliability can be expected from the different types of monitoring technologies over the range of expected monitoring conditions. Flow measurement during peak WWF conditions can vary from the actual flow by 20% or more.

The overall issues in flow monitoring are accuracy and reliability of the technology and interpretation of results. Improved accuracy of measurements, or at least an indication of error producing flow conditions, monitor fouling, etc., could be possible by installing multiple sensors that provide redundant measurements of the same quantity and use different physical principles and/or sensor placement. Miniaturization may be able to offset cost increases from the multiple sensor approach. Wireless, miniaturized sensors would be able to be deployed in more locations through a pipe network and hence provide a better picture of actual flow conditions and locations of problems. To be able to use such sensors, internal data storage, wireless data transmission and energy provision problems would need to be addressed.

2.2. Physical condition assessment

Increased flows at the treatment plant and SSOs indicate a problem, but do not isolate its location. A thorough assessment of the physical condition of the collection system is critical for repair or replacement and important to maintain the integrity of the system and to control I/I and exfiltration. An assessment identifies structural features that may require correction and aids in establishing priorities for rehabilitation or replacement of system components. The likelihood of failure and the associated risk analysis is intrinsic in the evaluation when budgetary restraints affect the work.

2.2.1. Gravity flow systems

Pipeline defects can be generated during installation (deflections, punctures, cracks, rolled joints, poor bedding/backfill material, etc.) or over time (corrosion, erosion, deterioration of grouts and joints, root penetration, thermal and nonthermal stresses or strains, soil subsidence, etc.). Inspection is usually done by smoke testing, man entry, flow isolation, dye-water flooding, and closed circuit television (CCTV); results are very observer-subjective. Dye and smoke test methods frequently cannot locate small leaks. Most currently available automated pipe inspection systems have limited capabilities. Varying pipe diameters, materials (including brick, concrete, ductile iron, and clay), odd shapes, sumps, and angle entries are not frequently suitable for CCTV inspection systems. Physical inspection by workers is costly, disruptive to urban commerce and travel, limited by pipe size, and potentially dangerous to personnel and surrounding structures.

2.2.2. Pressure systems

Force mains do not get inspected regularly because they operate under pressure and are generally critical sewers that do not experience significant periods of low/no flow. Inspection of their physical condition often takes place during downtime repairs of adjacent pipe segments. Inspection techniques are limited because of pipe size and accessability. In many cases, the only access points are at either end of the main.

2.2.3. Appurtenances

Physical inspection of manholes and junction chambers is performed by either surface inspection or by entering for internal inspection. Pump stations are typically inspected regularly as part of routine maintenance. Because of the hazardous atmosphere and flow conditions near siphons, only surface inspection of inlet and outlet structures is performed unless there are known or suspected problems in the siphon.

The primary research issue associated with physical condition assessment is how to effectively detect and locate defects/failures in wastewater collection systems to prevent I/I, exfiltration, and collapses which can cause street surface hazards and pipeline blockages. Although progress has been made in better defining inspection procedures and techniques since passage of the CWA, there is still a need to standardize and improve approaches. Nearly all inspection techniques depend on visual observation; defects may be missed or misinterpreted. One of the greatest limitations is interpretation of defect severity.

Various technologies have been and are being developed in Europe, Japan, and the United States to increase the reliability of information available from pipeline inspection. These new technologies include: sewer scanner and evaluation technology (SSET), sonar, seismic resurgence testing (SRT), acoustic testing, and infrared thermographic investigations. These technologies are designed to provide additional information such as depth of corrosion, sludge buildups, size and severity of cracks, wall thickness, ovality, etc., beyond what is available from conventional CCTV inspection (Thomas and Laszczynski, 1997). There is an overall need to evaluate these new technologies, along with CCTV, to document their performance and costs under both controlled-condition testing and field testing for a variety of applications; e.g., gravity systems, pressurized systems, house/service laterals, manholes and pumping stations. There is also a need to investigate the concept of "intelligent systems" for remote sensing and monitoring of the structural integrity of systems. The results of these efforts will provide the information and tools to move forward toward designing systems of a more sustainable nature.

A current research project in this area involves the development of predictive tools or performance indicators for measuring the degradation of sewer systems (Water Environment Research Foundation, 1999). The results of this work will enable municipalities to identify probable areas for rehabilitation prior to inspection based on a greater understanding of the variables that lead to failure. Inspection and detection programs can then be strategically focused in those areas that most likely need attention. Another project, which could have direct application to reinforced concrete sewerlines, is developing a remote system that utilizes electrochemical impedance techniques and electrochemical polarization decay for monitoring corrosion in underground pipes, piles, and steel encased in concrete (US Army Corps of Engineers, 1996a). The application of this technology could reduce/eliminate the need for costly "dig-ups" presently required to determine the corrosion status of underground pipes. In addition, application of the technology will provide valuable information on the actual mechanical process of corrosion.

3. Operation, maintenance, and rehabilitation

The objective of pipeline system operation, maintenance, and rehabilitation is to ensure the overall viability of the conveyance system by (1) maintaining structural integrity, (2) limiting exfiltration and its potential for groundwater contamination and other negative environmental impacts, and (3) reducing the amount of extraneous flows (I/I).

Effective maintenance and rehabilitation programs require a complete understanding of the condition and performance of a system and any other contributing factors. Pipe age is a factor; however, it is usually a combination of several factors that causes failures and influences maintenance decisions, making the situation very complex. Soil conditions, stress conditions, groundwater levels, sewage/soil acidity, dissolved oxygen levels, and electrical and magnetic fields may negatively impact long-term performance of the system. Pipe materials, and bedding and backfill materials are also factors. Decision factors should include an evaluation of both internal conditions, based on some form of visual inspection, and conditions surrounding the pipe. Decision support tools that incorporate pipe assessment methodologies are required to quantify and rank the condition of a pipeline based on structural, hydraulic, water quality and economic factors.

Pipeline rehabilitation procedures usually involve some form of cleaning to remove foreign materials before other phases of rehabilitation. The removal of roots, sediments, and debris is necessary for maintaining proper flow conditions and for reducing infiltration and exfiltration and structural damage to the pipeline. Common rehabilitation methods of chemical and cement grouting address problems associated with groundwater movement, washouts, soil settlements, collapses, and soil voids. Grouting is effective in reducing or eliminating infiltration but will not significantly improve the structural condition. It does, however, help stabilize the surrounding soil mass. Other approaches include sliplining, spiral-wound pipe, segmented liner pipes, cured-in-place pipe (CIPP), fold and form pipe, close-fit-pipe, pipe bursting, coatings, mechanical sealing devices, spot repair, and replacement. Many rehabilitation methods (other than grouting or sealing and pipe bursting) reduce pipe cross-sectional area and can reduce hydraulic performance. Such reduction is frequently acceptable, but must be taken into account in the rehabilitation evaluation (Water Environment Federation, 1994). New methods of sewer sealing should be evaluated before major rehabilitation or replacement is undertaken. Replacement is expensive, especially in older systems which tend to crack, crumble, deteriorate, and erode. Newer “trenchless” rehabilitation technologies should be considered to reduce the costs and inconvenience associated with traditional open-cut methods of pipe repair and replacement.

Failures in ***force mains*** can result in the release of large amounts of sewage within a short period. This can cause a rapid spread of contamination and potential health hazards. The rehabilitated force main pipes must be structurally stable within the surrounding soil mass, must not leak at operating pressures, must have adequate capacity to carry its design flows, and must be serviceable under the other conditions it will experience (e.g., sulfide corrosion). The most common rehabilitation method practiced on force mains is point repair of individual failed or failing line segments.

Building connections to the street sewers (house or service laterals) can contribute as much as 70 to 80% of the infiltration load (Field and Struzeski, 1972). Fluctuating ground water, variable soil characteristics and conditions, traffic, erosion, washouts, etc., cause enormous stresses on house/service lateral pipes and joints. Connectors and fittings in many cases do not retain their watertight integrity while adjusting to these factors. Some connections react to soil acid and may totally disintegrate in a few years. These conditions often result in generating major points of infiltration at the connection of the house/service lateral to the street lateral or main. With current technology, rehabilitating building connections may not be economically feasible because of the shear number of connections. The problem is both critical and sensitive because of private ownership and costs associated with disturbance to the occupant and destruction of valuable landscaping. Because of this, municipalities are often reluctant to address I/I problems from these sources. When performed, rehabilitation is done by point repair or replacement; sliplining and pipe bursting are also in limited use. However, these approaches do not overcome the private ownership problem or the problems associated with the location and configuration of the line (i.e., sharp bends). In addition, it is significant to mention that past studies have found that rehabilitation of sewerlines at the street alone does not completely solve the I/I problem (USEPA, 1985). Successive rainfalls can elevate the groundwater table to levels where entry occurs through the house laterals.

Rehabilitation of ***appurtenances*** (e.g., manholes, pump stations, wet wells, siphons) is an important component of both assuring sustainability of collection systems and of an I/I control strategy. About 30 to 50% of system I/I is due to defects and conditions in or near appurtenances, in particular, manholes (Perez, 1996). For example, manhole covers submerged in one inch of water can allow as much as 75 gpm (4.73 l/s) to enter the system depending on the number and size of holes in the cover (ASCE and WPCF, 1982). Rehabilitation of manholes, pumping stations, and wet wells includes spray-on coatings, spot repairs, structural liners, and replacement. Rehabilitation of siphons includes some of the options available for pipelines such as grouting and lining. Many siphons have been rehabilitated using either CIPP or high density polyethylene (HDPE) liners.

Selection of rehabilitation methods and materials suitable for various parts of the wastewater collection system remains an issue. The issue is partly related to the lack of understanding of the capabilities of each method relative to the problem. In addition, reliable rehabilitation product performance under actual field conditions is lacking. Data on the effectiveness and longevity of rehabilitation technologies and materials and life-cycle cost information will be useful in determining whether rehabilitation or replacement is more cost effective.

A range of trenchless technologies has been developed for rehabilitating most types of pipelines. New processes and products come to the market continually. Many are proprietary systems and the details of installation procedures and materials are trade secrets, limiting the ability to compare and evaluate competing approaches. For some techniques, codes and standards have been developed; however, because of the rapidly evolving technology in rehabilitation, standards and codes often lag behind. Some of these technologies are over 20 years old; in some cases original patents have expired and a number of “look-alikes” have appeared.

The fundamental research issues in this area relate to the selection of the most cost-effective approach to operate, maintain, and manage existing sewer systems to reduce I/I and exfiltration. Some specific needs include:

- determining the longevity and performance of various rehabilitation methods and various conditions that will provide comparative data on the cost effectiveness of each method;
- evaluating new and improved repair and replacement methodologies;
- evaluating approaches to optimize and assess O&M programs;
- developing alternative technologies for rehabilitation of house/service laterals and connections;
- evaluating the performance of grouts and liners under various environmental conditions such as humidity, temperature, pH, and wastewater chemistry;
- evaluating alternatives to remove roots and prevent root growth; and
- evaluating cost-performance tradeoffs between rehabilitation and replacement alternatives.

To date very little effort and resources have been directed at assessing the problem of exfiltration from sewerlines, mainly because the national concern has been in the area of direct impacts from combined and sanitary sewer overflow. An ongoing project is attempting to quantify on a national basis the magnitude of the exfiltration problem in wastewater collection systems: identify contributory factors to the problem; document approaches for correcting the problem; and identify technology gaps and research priorities (USEPA, 1998b).

Predictive methodologies are being developed to determine peak flows after sanitary sewer rehabilitation (Water Environment Research Foundation, 1999). These methodologies will provide information on the reductions in peak flows associated with approaches to I/I reduction. This will enable agencies to more accurately assess the progress and results of current

I/I programs as well as to plan more cost-effective programs.

Methodologies are also being developed to evaluate and optimize the effectiveness of sewer maintenance programs. One approach will provide information on how to: (1) establish an effective O&M program to maintain functional and structural integrity in the collection system; (2) evaluate the adequacy and effectiveness of an existing O&M program; and (3) prevent new connections/reconnections of inflow sources (USEPA, 1998c). Another will result in decision-making methodologies which can be used by cities and agencies to evaluate maintenance costs and system performance (USEPA, 1999a). This approach will provide information on how to: (1) evaluate the effectiveness of maintenance and rehabilitation programs by reviewing inspection activities; (2) review how maintenance and rehabilitation dollars are spent; and (3) provide typical values for maintenance frequencies and system reinvestment expenses to serve as benchmarks for local governments and agencies in evaluating their own programs.

A project, just initiated, will document European approaches for diagnosing and analyzing wastewater collection systems (USEPA, 1999b). Information will be collected on new and improved methodologies that assess the condition of a system and evaluate corrective action alternatives. Best management practices for a well operated and maintained system will be identified, including information on which pipe materials offer the best long-term behavior based on performance, reliability and repairability. The use of performance indicators to compare and improve O&M, and the need for related standard terminology, definitions and data collection and storage will also be investigated. In addition, a document will be prepared on the identification and assessment of existing “non-hydraulic” models for predicting failures in wastewater collection systems and for otherwise managing and optimizing the O&M of these systems.

The U.S. Army Corps of Engineers has evaluated a trenchless pipe insertion method developed by the gas industry in the United Kingdom for installing pipelines into existing, older lines, with limited excavation (US Army Corps of Engineers, 1996b). The technology, known as "pipe bursting", involves destroying the pipe in place and forcing it into the surrounding soil with an impact mole. Equipment is then used to push or pull a new pipe into the cavity created by the impact mole. The result is a pipe which follows the existing sewerage collection route from manhole to manhole. This technology as well as other trenchless approaches have experienced more widespread use and acceptance in the last seven years. The Trenchless Technology Center of Louisiana Tech University, Rustin, LA is involved in extensive research on materials and methods used in both trenchless rehabilitation and construction (Trenchless Technology Center, 1999).

The Center for Innovative Grouting Materials & Technology at the University of Houston, Houston, TX has constructed a test facility to evaluate coatings and liners for concrete and clay brick wastewater sewers/appurtenances. New products are tested to evaluate their ability to maintain a bond with the concrete surface under pressurized conditions (to simulate groundwater conditions). Products are applied to the concrete media (wet/dry) and tested to 15 psi (equivalent to a pipe sitting in 32 ft of water). Over a period of five months of testing, two of the coatings out of eight developed fine cracks. In addition, chemical resistance of the product is tested with and without holidays (pinholes) by immersing a coated concrete sample in a 3% sulfuric acid solution (to simulate worst possible sewer conditions) and a 30% sulfuric acid solution (to simulate long-term performance). The impact of the pinholes and whether or not the presence of a pinhole in a coating results in significant deterioration of the concrete surface beyond the coating is evaluated. Specimens in 3% and 30% sulfuric acid showed an increase in weight of 0.6 and 1%, respectively. With the increase in weight, blisters were formed around the pinholes leading to cracking of some of the coatings. The program includes field testing in actual collection systems (Vipulanandan et al., 1996).

4. New construction

Improved materials and construction techniques could reduce future rehabilitation needs as sewer systems age. Concrete pipe (with or without a protective layer of clay tiles/bricks) and vitrified clay pipe (VCP) have been used in the United States since initial sewerlines were installed (early 1800s). Concrete can corrode from sulfuric acid formation, and VCP, virtually inert to sulfuric acid, historically had problems due to leaking joints, short segment lengths, and brittleness. These pipes are gradually being replaced with plastic materials such as HDPE, polyvinyl chloride (PVC), reinforced plastic mortar (RPM), centrifugally cast fiberglass reinforced plastic mortar (CCFRPM), polymer concrete, and acrylonitrile-butadiene-styrene (ABS). Plastic materials are normally chemically resistant to domestic sewage; however, they can also cause problems since they are not rigid and tend to creep over time. Newer pipe joints provide watertight and root free service. Cement lined, coal tar/asphalt coated, and plastic lined concrete pipes have been used for larger diameter pipelines. RPM, CCFRPM, and polymer concrete pipes are gradually entering the market.

The physical impairment of pipeline systems can result from a wide assortment of causes. Older pipes used jute, wax, cement or asphalt/tar packed or grouted joints, which over time, deteriorate. Some joints are out-of-round or cracked or broken when installed, allowing for root penetration and subsequent infiltration. Some pipes were installed without proper bedding or backfill material, resulting in the common broken-back failure and/or pipeline sags.

The relationship between the chemistry of sewage to the pipe materials conveying it is of primary concern in the selection of pipe materials. Normal domestic sewage has a pH of 6 to 8. However, domestic sewage contains bacteria, sulfate, and organic matter which generates sulfides. In the presence of water, sulfides immediately convert to hydrogen sulfide gas, which is slightly heavier than air. The hydrogen sulfide gas finds its way into the sewer atmosphere and comes into contact with the moist surface of the pipe crown, where it is rapidly oxidized by bacteria into sulfuric acid. Sulfuric acid is highly corrosive to many piping materials.

Pipes are normally installed using open trenching methods. As mentioned earlier, trenchless replacement and construction techniques have been gaining popularity. These methods include: pipe bursting; micro tunneling; directional drilling; pipe jacking; plowing in; and fluid jet cutting (Water Environment Federation, 1994).

Most I/I comes from faulty house/service laterals, especially from coupling between house service and street laterals due to differential settling. Most service laterals installed today are plastic pipes with either rubber-ring slip joints or solvent-welded joints. Solvent-welded joints are preferred because they resist root intrusion better than rubber-ring slip joints. The pipe wall thickness must be great enough to resist damage by rodents and crushing or fracture from heavy loads (automobiles, trucks, plows, tractors, etc.).

Current force main construction and replacement materials include ductile iron, steel, and concrete (typically prestressed concrete) pipe. The use of plastic materials is increasing. Corrosion continues to be the problem for all metallic, as well as prestressed concrete pipes. Improved standards and materials of construction are required to realize quality improvements and sustainability of products.

Current construction practices for manholes typically include precast lined or unlined concrete sections with a formed joint sealed with a butyl-type rubber seal. Manholes are usually placed about every 300 to 400 feet (90 to 120 meter), at changes in pipe diameter, direction and elevation, or where two or more pipes have to be joined into one pipe. With the current population growth rate, about 300,000 to 400,000 new manholes are constructed each year. Corrosion of concrete remains an issue for all appurtenances and corrosion protection is required in areas of high hydrogen sulfide. I/I occurs even in new manholes through defects at pipe seals, wall joints, chimney joints, and covers. Because manholes are a large contributor of I/I, the spacing of manholes is an issue. Increased spacing reduces the number of manholes, but increases the lengths of pipes between manholes, frequently making maintenance more difficult. Proper bedding and placement of manholes are critical to avoid differential settlement failures at pipe-manhole connections. Design engineers must consider these issues when designing wastewater collection systems. Removing covers during routine maintenance often results in improperly placed covers and increased stormwater runoff entry. Depressed manhole covers also provide a source for stormwater entry. Alternative designs for watertight manholes have been developed; additional research into the cost effectiveness of these designs should be performed.

The primary research issues in this category are associated with the application of new and improved design, construction, and installation technologies and materials to improve the quality and the long-term effectiveness of the installed product. Research needs include:

- identifying materials that could be incorporated into pipe materials and coatings that could control corrosion and increase strength;
- developing materials/sensors that could be incorporated into piping systems as "smart materials" for which it is possible to track deterioration or structural performance over time;
- evaluating new designs for cost-effective watertight manholes;
- evaluating the long-term performance of the various plastic pipes now being used for force mains;
- reviewing and evaluating current sewer design and installation practices (including materials for improved structural performance);
- evaluating new and improved coupling techniques and house service laterals to significantly alleviate I/I and exfiltration problems;
- determining whether solvent-welded pipe is better than rubber-gasketed pipe for long-term I/I and root control in house/service laterals.

An ongoing research project is investigating innovative materials and techniques that could be used to advance the state-of-the-art for new and replacement sewer collection systems. The focus of the work is on: design and construction practices; techniques and materials introduced or under research in the United States and other countries; new installation and jointing techniques; and developments in design concepts, technologies and materials used for sewer rehabilitation. The final document will provide a resource to review alternative replacement technologies and new design, materials, and construction practices (Water Environment Research Foundation, 1999).

5. Summary

The rehabilitation of sewers across the United States has experienced substantial growth for many years, in response to both political pressures and technical developments. The deteriorating underground sewer network threatens the environment, public health, and safety. Over the past decade, many improvements have been made to the nation's wastewater piping system; however, much more work still needs to be done. Leaking sewer systems can contaminate water supplies, while SSOs may discharge into rivers and oceans. Each year problem systems make the newspaper headlines when a road collapses due to a break or faulty pipe section. The piping systems in many parts of the country are overused and overworked, resulting in a higher frequency of breakdown or failure. The demand to maintain and upgrade the wastewater piping network continues and new methods are required to improve their performance more cost effectively. The sewer system is a national asset; the value of this asset is more than one trillion dollars and it cannot be easily replaced. There are well-established design methods and materials to deliver high-quality performance for both new pipe installation and rehabilitation of existing networks. However, new thinking about pipe design, new technologies and new materials, both in the United States and in other parts of the world, offer opportunities for improving upon traditional methods as well as providing alternative solutions.

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